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EFFECT OF BARITE ON MEIOFAUNA IN A FLOW-THROUGH EXPERIMENTAL SYSTEM

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ABSTRACT

The effects of barite (94–96% $BaSO_4$), a major constituent of drilling muds used in marine oil drilling operations, on meiofauna were studied in an experimental flow-through system. Aquaria containing sand or varying proportions of barite and sand received a continuous supply of unfiltered seawater from Santa Rosa Sound, Florida, for ten weeks. At the end of this period the composition, biomass and vertical distribution of the meiofauna were determined. Most of the meiofauna (>99%) occurred in the highly aerobic upper 2 cm portion of the substratum. Rotifera, Foraminifera, Hydrozoa, Turbellaria, Ostracoda, Polychaeta and Bivalvia did not exhibit significant differences between control and experimental aquaria, However, the densities of Nematoda, Copepoda and Copepoda nauplii varied with the substrate composition. The meiofaunal densities in the aquaria containing 1:10 or 1:3 mixtures of barite and sand were greater than that in aquaria containing sand alone. A marked decrease in meiofaunal density was evident in aquaria containing 5·5 cm of sand covered with a 0·5 cm layer of barite.

INTRODUCTION

Barite (94–96% $BaSO_4$) is a major component of the drilling muds used in oil exploration in the marine environment. Although a large percentage of drilling mud is recovered and recycled, tons may be deposited on the bottom near oil well drilling sites (Shinn, 1974). Barite has not been shown to have a toxic effect on aquatic

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organisms (Daugherty, 1951; Cabrera, 1971; Grantham & Sloan, 1975; George, 1975). However, the deposition of barite on the bottom may dramatically alter sediment granulometry and reduce percolation of oxygenated water into the sediment. This could have a potential impact on benthic organisms such as meiofauna which inhabit the interstices of marine sediments. Consequently, our study was initiated to determine the effects of barite on meiobenthic communities established in the laboratory.

MATERIALS AND METHODS

A flow-through experiment using the system described by Hansen (1974) was conducted with benthic communities at the Gulf Breeze Environmental Research Laboratory. Each aquarium (56 cm long, 9 cm wide and 12 cm high) was filled to 6 cm with either sand or sand and barite ($BaSO_4$). The sand consisted of a mixture of 25% coarse sand and 75% medium grain sand. Four aquaria (A, B, C and D) were used in the present investigation. Aquarium A served as the control and contained only sand; aquarium B had a mixture of one part barite and ten parts sand by volume (1:10); aquarium C had one part barite and three parts sand by volume (1:3) and aquarium D had 5·5 cm of sand covered with a 0·5 cm layer of barite. Seawater levels in the aquaria were maintained at 9 cm (3 cm above the substrate) by pumping unfiltered seawater continuously for ten weeks (17 August–26 October, 1976) from Santa Rosa Sound, Florida. The rationale for using unfiltered seawater is that it brings in various organisms which may establish themselves in the experimental system. The flow rate of water through each aquarium was 12 litres/h.

After ten weeks, three cores (3·5 cm inside diameter) were taken to a depth of 6 cm from each aquarium. The cores were sectioned at 2 cm to yield a 0 to 2 cm layer and a 2 to 6 cm layer. Each layer was preserved in buffered 5% formalin and Rose Bengal (0·3 g of Rose Bengal per litre of 5% formalin). The sediment was transferred to a one-litre Erlenmeyer flask and agitated with tap water. After allowing the heavier particles to settle for a few seconds, the supernatant was poured through a 55 μm mesh nylon sieve. This decantation procedure, repeated four times, yielded better than 99% extraction efficiency for the organisms considered in this study. The meiofauna retained on a 55 μm sieve was washed into petri dishes, sorted and counted. Nematodes were transferred to a nine-hole porcelain spot-plate containing a 3% aqueous glycerin solution for a week of infiltration before being transferred to a mounting medium of anhydrous glycerin for the preparation of permanent slides. The diameter of each core was 3·5 cm; therefore, the extrapolated densities were multiplied by 1·039 to obtain individuals $10\,cm^{-2}$. Wet weights of nematodes were calculated by various body measurements and an assumed specific gravity of 1·13 (Wieser, 1960). Faunal affinities between control and experimental aquaria were examined by using the Czekanowski coefficient (Field & McFarlane, 1968).

In addition to meiofauna cores, two cores were also taken from each aquarium for determinations of sediment granulometry and interstitial water content in the 0 to 2 cm layer. The wet sediment in the 0 to 2 cm layer was weighed and dried at 110 °C to constant weight. The dried sediment was then analysed for granulometric properties according to the methodology outlined by Krumbein & Pettijohn (1938).

Sediment oxidation-reduction potential (Eh) was measured at 1 cm intervals with a saturated calomel half cell as a reference and a platinum indicating electrode (Riedl & Ott, 1970). The electrodes for Eh measurements were calibrated with a standard redox solution (Zobell, 1946).

Data from control and experimental aquaria were subjected to a two-way analysis of variance (ANOVA) based on $\log_{10}(x + 1)$ transformed values. All percentage data were transformed to arcsin functions before conducting the ANOVA. When appropriate, the two-way analysis of variance was followed by the Duncan's multiple range test (Sokal & Rohlf, 1969). Differences were considered significant at p values of 0·05 or less.

RESULTS

Environmental parameters

During the experiment, the salinity and temperature averaged 26·5‰ (range 22·5–30‰) and 25·5 °C (range 17·0–30·5 °C), respectively. There were no significant differences ($p > 0{\cdot}05$) in sorting or medium grain size among control and experimental aquaria. Each aquarium contained a well-sorted (1·27) medium sand (0·41 mm median grain size).

The only significant difference in granulometry among the aquaria was in the percentage of silt-clay content. The median grain size of barite was less than 60 μm; results of sediment granulometry showed no silt-clay in control aquaria without the addition of barite. The percentage of silt-clay found was 5·6%, 16·3% and 15·1% in aquaria B (1:10 mixture of barite and sand), C (1:3 mixture of barite and sand) and D (covered with 0·5 cm barite), respectively. There were no significant differences ($p > 0{\cdot}05$) in percent silt-clay between aquaria C and D, but these aquaria contained significantly higher ($p < 0{\cdot}01$) percentages of silt-clay than either aquarium A or aquarium B. In addition, aquarium B (1:10 mixture) had a significantly higher ($p < 0{\cdot}01$) percentage of silt-clay than aquarium A (control).

The results of Eh and interstitial water content showed no significant ($p > 0{\cdot}05$) differences in either of these parameters in the 0 to 2 cm layer among control and experimental aquaria. The 0 to 2 cm layer was well oxidised (+241 mv) and had ample interstitial water (22·9%). Significant vertical differences did occur, however, in the redox profiles (Table 1). The Eh decreased with increasing depth in the control aquarium and in the aquaria containing a cover of barite or a 1:10 mixture of barite and sand. This pattern is similar to the redox profile observed for natural sandy

TABLE 1

Eh PROFILES (MV) IN THE CONTROL AQUARIUM A (SAND) AND EXPERIMENTAL AQUARIA B (1:10 MIXTURE OF BARITE AND SAND), C (1:3 MIXTURE OF BARITE AND SAND) AND D (5·5 CM SAND SUBSTRATE COVERED WITH 0·5 CM LAYER OF BARITE). EACH VALUE GIVEN IS AN AVERAGE OF TWO MEASUREMENTS AT EACH DEPTH

Depth (cm)	*Control*	*Experimental aquaria (barite)*		
	A	*B*	*C*	*D*
Overlying water	+265	+268	+280	+300
1	+245	+248	+275	+247
2	+237	+200	+265	+212
3	+190	+167	+255	+185
4	+170	+147	+250	+165
5	+160	+140	+242	+152
6	+157	+132	+240	+150

substrata elsewhere (Tietjen, 1969; Fenchel, 1969; Wieser *et al.*, 1974). However, the aquarium containing the 1:3 mixture of barite and sand did not exhibit as marked a decrease in Eh with increasing depth.

The meiofauna

A majority (>99%) of the meiofauna was encountered in the 0 to 2 cm layer. Numerical abundances of each taxon are given in Table 2. Total meiofaunal densities were significantly higher ($p < 0{\cdot}05$) in aquaria B (1:10 mixture) and C (1:3

TABLE 2

COMPOSITION OF MEIOFAUNA IN CONTROL (A) AND EXPERIMENTAL AQUARIA B (1:10 MIXTURE OF BARITE AND SAND), C (1:3 MIXTURE OF BARITE AND SAND) AND D (SAND SUBSTRATE COVERED BY 0·5 CM LAYER OF BARITE). THE VALUES GIVEN (MEAN ± STANDARD ERROR) REPRESENT THE NUMBER OF INDIVIDUALS 10 CM^{-2} AND ARE BASED ON THREE CORE SAMPLES FOR EACH TREATMENT

Taxonomic group	*Control*	*Experimental aquaria*		
	A	*B*	*C*	*D*
Nematoda[a]	725 ± 123	1538 ± 186	1018 ± 83	165 ± 42
Copepoda Harpacticoida[b]	89 ± 40	172 ± 33	108 ± 39	24 ± 9
Copepoda nauplii[b]	35 ± 16	82 ± 21	115 ± 25	12 ± 10
Rotifera	69 ± 36	245 ± 128	816 ± 245	564 ± 233
Foraminifera	60 ± 34	6 ± 6	13 ± 10	7 ± 3
Hydrozoa	12 ± 8	14 ± 8	13 ± 10	21 ± 10
Turbellaria	0 ± 0	19 ± 5	5 ± 5	10 ± 10
Ostracoda	0 ± 0	0 ± 0	4 ± 2	0 ± 0
Polychaeta	42 ± 23	3 ± 3	0 ± 0	2 ± 2
Bivalvia	0 ± 0	0 ± 0	7 ± 7	3 ± 3
Total densities[c]	1032 ± 167	2079 ± 251	2099 ± 145	808 ± 287

[a] Significantly different ($p < 0{\cdot}05$) for D versus A; D versus B; D versus C and control (A) versus B (1:10).
[b] Significantly different ($p < 0{\cdot}05$) for D versus B and D versus C.
[c] Significantly different ($p < 0{\cdot}05$) for A versus B; A versus C; D versus B and D versus C.

mixture) than in the control aquarium (A). The total meiofaunal densities were significantly lower ($p < 0.05$) in the aquarium with a substrate cover of barite (D) than in aquaria containing 1:10 (B) or 1:3 (C) mixtures of barite and sand. Nematode densities were significantly lower ($p < 0.05$) in the aquarium with a cover of barite than in the other aquaria. Nematode densities in the aquarium containing the 1:10 mixture of barite and sand were higher than those in the control aquarium. The calculated nematode biomass (milligramme wet weight) exhibited variations similar to those of nematode densities. The biomass of nematodes in the aquaria was as follows: control, 0.502 ± 0.104 (mean $\pm$ standard error); 1:10 mixture of barite and sand, 1.001 ± 0.029; 1:3 mixture of barite and sand, 0.744 ± 0.133; substrate covered with barite, 0.113 ± 0.078. Copepoda and Copepoda nauplii had significantly lower densities in the aquarium with a cover of barite compared with the aquaria with mixtures of barite and sand. Other groups, including Rotifera, Foraminifera, Hydrozoa, Turbellaria, Ostracoda, Polychaeta and Bivalvia, did not exhibit significant differences between control and experimental aquaria.

TABLE 3

ABUNDANCE OF NEMATODE SPECIES IN CONTROL (A; SAND) AND EXPERIMENTAL AQUARIA B (1:10 MIXTURE OF BARITE AND SAND), C (1:3 MIXTURE OF BARITE AND SAND) AND D (SAND SUBSTRATE COVERED BY 0·5 CM OF BARITE). THE VALUES GIVEN (MEAN $\pm$ STANDARD ERROR) REPRESENT THE NUMBER OF INDIVIDUALS $10\,cm^{-2}$ AND ARE BASED ON THREE CORE SAMPLES FOR EACH TREATMENT

Species	*Control*	*Experimental aquaria*		
	A	*B*	*C*	*D*
Chromadora nudicapitata Bastian	83 ± 61	0 ± 0	22 ± 22	0 ± 0
Microlaimus problematicus Allgen[a]	203 ± 124	735 ± 77	396 ± 48	54 ± 11
Monhystera parva	24 ± 7	160 ± 44	202 ± 75	36 ± 24
Monhystera sp. 2	13 ± 5	24 ± 24	9 ± 4	15 ± 8
Monhystera sp. 3	0 ± 0	9 ± 9	38 ± 19	10 ± 2
Chromadorita sp. 1	2 ± 2	19 ± 19	0 ± 0	0 ± 0
Prochromadorella micoletzkyi Chitwood[b]	74 ± 22	399 ± 120	223 ± 98	10 ± 7
Viscosia macramphida Chitwood	240 ± 96	145 ± 80	77 ± 44	20 ± 8
Eurystomina americana	26 ± 10	17 ± 17	0 ± 0	6 ± 4
Oncholaimus domesticus (Chitwood & Chitwood)[b]	19 ± 4	15 ± 8	48 ± 25	0 ± 0
Anoplostoma sp.[c]	19 ± 10	0 ± 0	0 ± 0	0 ± 0
Odontophora sp.	4 ± 4	0 ± 0	0 ± 0	0 ± 0
Anticoma sp.	4 ± 4	0 ± 0	0 ± 0	0 ± 0
Cyatholaimus sp.	11 ± 11	0 ± 0	0 ± 0	4 ± 4
Tricoma sp.	0 ± 0	8 ± 8	0 ± 0	2 ± 2
Tripyloides sp.	0 ± 0	7 ± 7	0 ± 0	0 ± 0
Leptolaimus sp.	0 ± 0	0 ± 0	4 ± 4	6 ± 4
Neonyx sp.	0 ± 0	0 ± 0	0 ± 0	2 ± 2

[a] Significantly different ($p < 0.05$) for D versus B; D versus C; D versus A and A versus B.
[b] Significantly different ($p < 0.05$) for D versus B; D versus C and D versus A.
[c] Significantly different ($p < 0.05$) for A versus B; A versus C and A versus D.

Since Nematoda was the most abundant taxon encountered in this investigation, the species of nematodes in the control and experimental aquaria were identified. No major shifts in nematode species composition were apparent, as evidenced by a lack of change in faunal similarity measured by the Czekanowski coefficients (Field & McFarlane, 1968). Of the 17 species encountered (Table 3), four—*Prochromadorella micoletzkyi*, *Oncholaimus domesticus*, *Microlaimus problematicus* and *Anoplostoma* sp.—exhibited significant changes and were primarily responsible for the observed differences in nematode densities between control and experimental aquaria. Significantly ($p < 0.05$) fewer individuals of *Microlaimus problematicus*, *Prochromadoreila micoletzkyi* and *Oncholaimus domesticus* were seen in the aquarium covered with barite compared with other aquaria. In addition, *Microlaimus problematicus* occurred in significantly higher ($p < 0.05$) densities in the aquarium containing the 1:10 mixture of barite and sand than in the control aquarium containing sand alone. *Anoplostoma* sp. showed significantly higher ($p < 0.05$) densities in the control aquarium compared with the experimental aquaria.

DISCUSSION

Although barite is generally considered non-toxic to most marine organisms, the addition of large quantities of barite mixed into or covering marine sediments may produce marked changes in sediment granulometry. Many meiofauna inhabit the interstices of marine sediments; thus, a marked change in sediment granulometry may influence the distribution and density of meiofauna. Sediment granulometry has been shown to be important in the distribution of many meiofauna groups, as reviewed by Delamare-Deboutteville (1960), Swedmark (1964), Jansson (1967) and McIntyre (1969), and is of fundamental importance both directly and indirectly in the ecology of marine meiofauna. Although no changes in median sand grain size or percent interstitial water were observed among the aquaria in our investigation, there were variations in the silt-clay content of experimental aquaria. As previously stated, the silt-clay content in the experimental aquaria is attributable to the barite present.

The total densities of nematodes in the aquarium with the 1:10 mixture of barite and sand were higher compared with the control aquarium. This may be due to an increased heterogeneity of the sediment. Increased concentrations of barite result in increased amounts of the silt-clay fraction and change the sediment in the aquaria from a homogeneous sand to a more heterogeneous substratum. The increased heterogeneity may allow some species a greater opportunity to partition the environment spatially and increase their densities. The increased number of nematodes in sand mixed with barite is consistent with the general view that the highest densities of nematodes tend to occur in sediments containing significantly greater quantities of silt-clay (Wieser, 1960; Tietjen, 1969; Juario, 1975).

In addition to the absolute percentage of barite in the upper 2 cm layers, the distribution of barite may also be important in explaining the differences in densities of meiofauna among the aquaria. For example, the aquarium (C) with the 1:3 mixture of barite and sand had the same percentage of barite within the upper 2 cm as that in the aquarium (D) with a 0·5 cm barite cover on top of the sand. However, the former aquarium had an even distribution of barite, whereas all the barite was concentrated in the upper 0·5 cm in the aquarium with the cover of barite. Thus, meiofauna living within the uppermost 0·5 cm would be exposed to a 100% barite environment. This may interfere with the feeding and locomotory activities of some species. Copepods have been found by Jansson (1968) to be very sensitive to interstitial space and greater densities of copepods are generally found in sandy substrata than in silty sediments. Movement of copepods and nauplii through 100% barite sediments, as found in the upper 0·5 cm in the aquarium (D) with the cover of barite, is probably more difficult than movement through sand or sand evenly mixed with barite. The copepod densities in the aquarium with a barite cover were lower than those in the control aquarium.

Significantly lower densities ($p < 0.05$) of Copepoda nauplii and Nematoda occurred in the aquarium with a cover of barite. The species of nematodes responsible for these lower densities—*Microlaimus problematicus*, *Prochromadorella micoletzki* and *Oncholaimus domesticus*—belonged to the families Desmodoridae, Chromadoridae and Oncholaimidae, respectively. Representatives of these families were also shown to be far less numerous in sediments containing high silt-clay contents in the natural environment (Wieser, 1960; Warwick & Buchanan, 1970; Ward, 1973; Lorenzen, 1974; Juario, 1975; Tietjen, 1977). Epigrowth feeders, such as *Microlaimus problematicus* and *Prochromadorella micoletzki*, generally feed by scraping off algae and other food materials from sediment particles or by puncturing algal cells and withdrawing the contents. In addition to piercing large cells, predator/omnivores such as *Oncholaimus domesticus* may ingest whole cells intact. Microscopic observations of the above species from the upper layer in the aquarium with the cover of barite revealed that their buccal cavities were filled with silt-clay (barite) particles. Whether such large quantities of barite interfere with the feeding activities of some nematodes by clogging the buccal cavity and *physically* interfering with the ingestion of food remains to be established.

In addition to the difference in meiofaunal densities between the experimental and control aquaria, there were significant vertical differences in meiofauna within each aquarium. More than 99% of the organisms occurred in the upper 2 cm. The 0 to 2 cm zone is also the area with the highest Eh values (aerobic) and greatest concentration of potential food resources. Similar vertical distribution patterns of meiofauna have also been found in nature by several investigators (Wieser, 1964; Teal & Wieser, 1966; Tietjen, 1969; Coull, 1970; Ott, 1967; Boucher, 1972; Harris, 1972; Giere, 1973; Wieser *et al.*, 1974).

In summary, an even mixture of barite and sand in proportions of 1:10 or 1:3 increased sediment heterogeneity and resulted in significant increases in the densities of meiofauna. However, when barite was deposited on the surface of the sediment, significant decreases in meiofauna were observed. Thus, barite deposited on top of the sediment from drilling well activities may significantly decrease total meiofaunal densities. Due to the importance of meiofauna in recycling of nutrients at lower trophic levels and enhancement of mineralisation of organic matter (Johannes, 1965; McIntyre, 1969, 1973; Marshall, 1970; Coull, 1973; Tenore *et al.*, 1977), significant decreases in total densities may have profound consequences on the structure and function of marine benthic communities. Although the authors are aware that increased replication of control and experimental aquaria is desirable, these preliminary studies indicate the potential disruptive effect of barite deposition on meiofauna communities.

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